

Deep Structure of the Texas Gulf Passive Margin and its Ouachita-Precambrian Basement: Results of the COCORP San Marcos Arch Survey¹

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ABSTRACT

This COCORP deep seismic survey provides a comprehensive image of the southeast-Texas part of the Gulf passive margin and its accreted Ouachita arc foundation. Beneath the updip limit of the Cenozoic sediment wedge, a prominent antiformal structure is imaged within the interior zone of the buried late Paleozoic Ouachita orogen. The structure appears to involve Precambrian Grenville basement. The crest of the antiform is coincident with the Cretaceous-Tertiary Luling-Mexia-Talco fault zone. Some of these faults dip to the northwest, counter to the general regional pattern of down-to-the-basin faulting, and appear to sole into the top of the antiform, suggesting that the Ouachita structure has been reactivated as a hingeline to the subsiding passive margin. The antiform may be tied via this fault system and the Ouachita gravity gradient to the similar Devils River, Waco, and Benton uplifts, interpreted as Precambrian basement-cored massifs.

Above the Paleozoic sequence, a possible rift-related graben is imaged near the updip limit of Jurassic salt.

Paleoshelf edges of the major Tertiary depositional sequences are marked by expanded sections disrupted by growth faults and shale diapirs. Within the Wilcox

Formation, the transect crosses the mouth of the 900-m-deep Yoakum Canyon, a principal pathway of sediment delivery from the Laramide belt to the Gulf.

Beneath the Wilcox, the Comanchean (Lower Cretaceous) shelf edge, capped by the Stuart City reef, is imaged as a pronounced topographic break overlapped by several moundy sediment packages. Because this segment of the line parallels strike, the topographic break may be interpreted as a 2000-m-deep embayment in the Cretaceous shelf-edge, and possibly a major submarine canyon older and deeper than the Yoakum Canyon.

INTRODUCTION

In early 1988 COCORP (Consortium for Continental Reflection Profiling) ran a deep seismic survey along the San Marcos arch in Texas to image the Proterozoic Grenville and upper Paleozoic Ouachita basement and its Mesozoic-Tertiary passive margin cover (Figures 1-3). The sixth in a series of deep seismic transects of the Appalachian-Ouachita orogen, and the fourth to cross the Grenville orogen, this survey was conceived to extend previous efforts to seismically map the three-dimensional crustal structure of eastern North America.

Prematurely truncated due to an interruption of funding, the survey presently consists of three 30-to 60-fold Vibroseis® lines totaling 250 km in length, extending from Port Lavaca on the central Texas coast to the southeastern edge of the Llano uplift (Figures 1-3) (Nelson, 1989). COCORP plans include extension of the survey northward across the Llano uplift. The data described here were acquired in early 1988 by a Seismograph Services Corporation (SSC) crew using a vibration point (VP) interval of 100 m for lines TX4 and TX5, and 200 m for line TX6, and a split spread of 120 receiver groups deployed at 100-m intervals. The record length was 20 s. Processing through final stack, including deconvolution, bandpass filter, AGC (automatic gain control), and coherency filter (for further details see Nelson, 1989), was done on the Cornell National Supercomputer Facility's IBM 3090 supercomputer. Interpretation was aided by a Landmark™ workstation.

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¹Manuscript received October 25, 1990; revised manuscript received May 28, 1991; final acceptance July 24, 1991.

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COCORP is funded by National Science Foundation Grant EAR-8609992. Seismic data were collected by Seismograph Services Corporation, processed on the Cornell National Supercomputer Facility IBM 3090, and interpreted on a Landmark™ workstation. Culotta's research was supported by a Shell Foundation Fellowship. We thank Gerard Bond, Peter Szatmari, Anthony Tankard, William Thomas, William Galloway, David Amsbury, R. W. Scott, Bill Muehlberger, and Robert Litak for helpful advice and comments on the manuscript. Institute for the Study of the Continents Contribution 153.

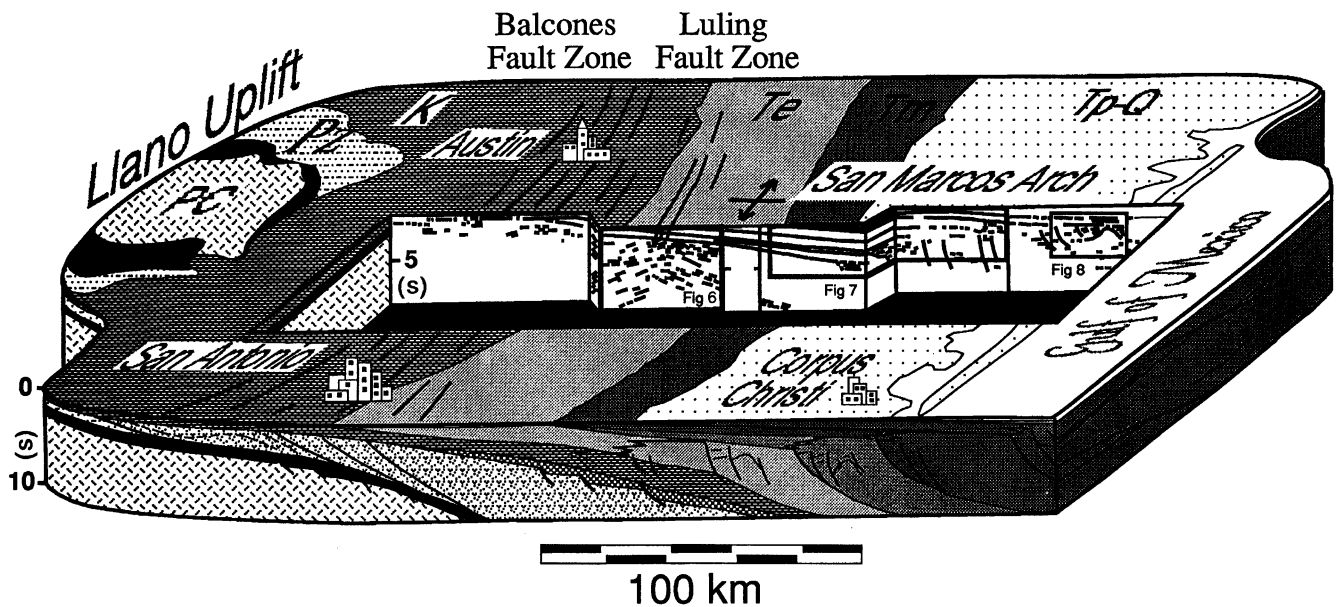


Figure 1—A schematic perspective view of the San Marcos arch study area, southeastern Texas, depicting a simplified line drawing of the upper 10 s of the unmigrated seismic data projected on the rear wall of an imaginary excavation. Heavy boxes indicate segments of seismic data displayed in Figures 5, 7, 8, as indicated. Displayed on the front face is a generalized geologic cross section, drawn from published seismic data (Ewing, 1986) and borehole studies (Flawn, 1961; Bebout et al., 1982; Galloway et al., 1986; Morton et al., 1988); the vertical axis is in seconds two-way traveltime. Basement involvement, as depicted in Figure 3 and discussed in the text, is not included on this cross section. The same patterns to delineate strata are used for Figures 2–6. Symbols: PC = Precambrian (Grenville), Pz = Paleozoic Ouachita foreland and allochthonous facies, K = Cretaceous, Te = Eocene, Tm = Miocene, Tp-Q = Pliocene and Quaternary. Normal faults are schematic. Cities are not to scale.

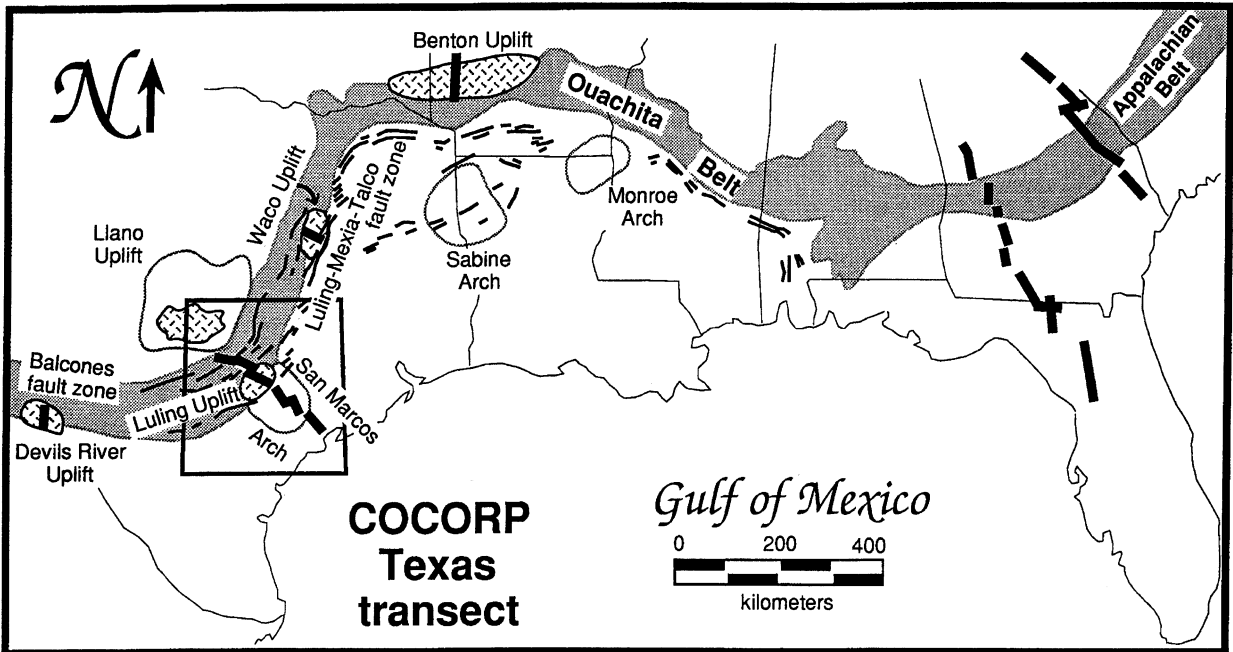
Although the petroleum industry has collected many seismic lines in this hydrocarbon-rich region, only a few seismic lines of short length and recording time have been published. Still, the stratigraphy along the COCORP transect is well constrained by a network of electric well logs, cores, and the available seismic data (Figures 2–5) (Flawn, 1961; Bebout et al., 1982; Galloway et al., 1982; Winker, 1982; Morton et al., 1988). In addition to imaging interesting features on each of the three lines individually, the COCORP transect may have special value in its comprehensive scope: extending from the Gulf Coast to the Llano uplift, it records much of the span of geologic time since the middle Proterozoic, including elements of two complete Wilson cycles. The transect illustrates on a grand scale the process of continental growth, alternately by tectonic accretion and sedimentary progradation.

The main stages of this evolution are well known from previous studies, e.g., Flawn (1961), Rose (1972), King (1975), Bebout et al. (1982), Winker (1982), Bufner and Sawyer (1985), Galloway (1989), and Viele and Thomas (1989). First, one or more terranes of the Grenville province were accreted to the Central Plains province during the Grenville orogeny at approximately 1.3–1.0 Ga, or possibly earlier. In the early Paleozoic, a rift formed within or along the southeastern edge of

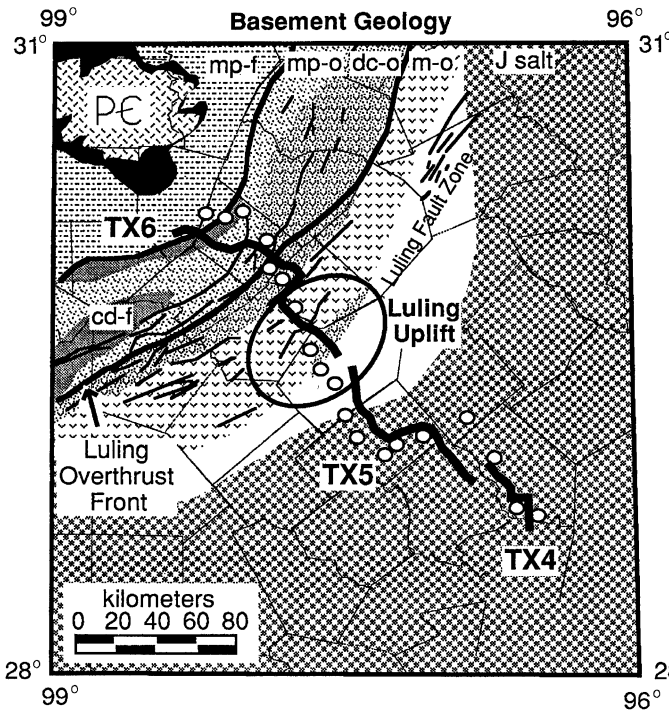
this Grenville terrane. An island-arc terrane then collided with this passive margin during the Pennsylvanian–Permian Ouachita orogeny. Finally, the accreted Ouachita rocks were rifted and buried beneath the Mesozoic–Cenozoic Gulf Coast passive margin sequence. The Precambrian Grenville and Paleozoic Ouachita belts are together considered “basement” to the Mesozoic–Cenozoic sediments.

Within this broad-brush tableau we recognize in the COCORP data a few key elements, some not previously reported: a large antiform, at the leading edge of the accreted Ouachita terrane, which probably correlates with basement massifs seismically imaged hundreds of kilometers to the northeast and southwest (Figures 1–3, 6); reactivation of this Ouachita structure as a tectonically and flexurally controlled hingeline for the Mesozoic–Cenozoic passive margin; a deep embayment—possibly a submarine canyon—at the edge of the Lower Cretaceous carbonate bank (Figures 3, 7); and the entire Tertiary series of offlapping depositional sequences with shelf-edge expansion zones marked by growth faults and shale diapirs (Figures 1, 3, 4, 7, 8). Sharp bends, required by detouring of roads past natural escarpments, provided significant crossline control on some of these features. The following discussion parallels the direction of propagation of tectonic and

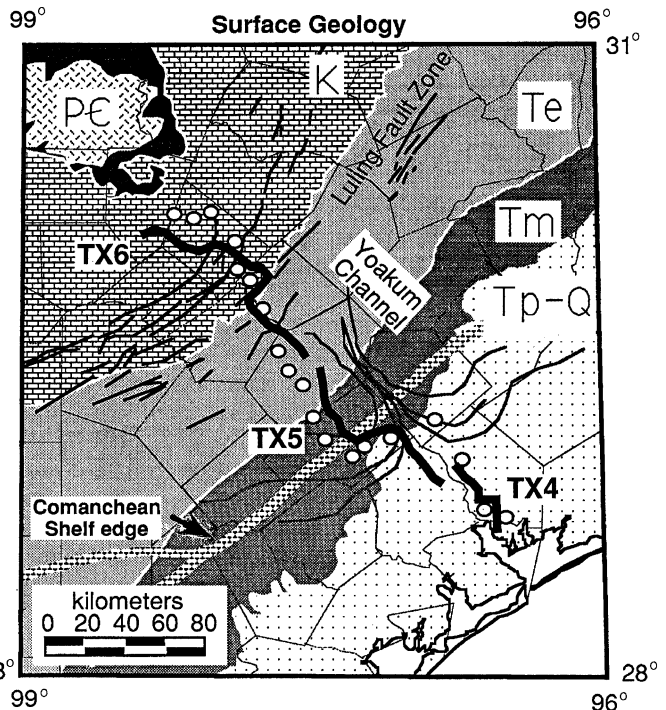
a



b



c



sedimentary processes, proceeding from northwest to southeast, and from oldest to youngest.

PRECAMBRIAN GRENVILLE PROVINCE

Line TX6 climbs onto the southeastern edge of the Llano uplift, the exposed core of which consists of

gneisses, schists, and metavolcanic rocks deformed and metamorphosed 1.15–1.0 billion years ago (McGehee, 1979; Barnes, 1988) (Figures 1–2). These dates and lithologies suggest involvement in the Grenville orogeny (approximately 1.3–1.0 Ga), making these the southwesternmost significant exposures of Grenville rocks in the United States. Recent deep seismic imaging of crustal scale shear zones within Grenville crust in Ohio,

Figure 2—(a) Regional map of Gulf Coast and southern Appalachian–Ouachita orogen. Locations of COCORP and industry seismic surveys are shown by bold black lines. Basement pattern (see Figure 1 for key to patterns) indicates uplifts known or presumed to be cored by Precambrian basement. Faults are shown by medium black lines. Box encloses San Marco arch study area, enlarged in b and c. (b) Basement geology of San Marcos arch study area, with Cretaceous–Tertiary section removed. Heavy black lines show the location of COCORP and industry seismic surveys, and open circles mark locations of wells with electric logs and cores reviewed in this study; all but the northwesternmost four wells are shown on Figure 4. Distribution and designation of Paleozoic units are from Flawn (1961): within the interior zone southeast of the Luling overthrust front probably are allochthonous units m-o (metamorphic Ouachita facies) and dc-o (dark carbonaceous Ouachita facies); unmetamorphosed rocks of the frontal zone include dc-o, probably parautochthonous mp-o (Mississippian–Pennsylvanian Ouachita facies) and cd-f (Cambrian–Devonian “foreland” facies), and foreland basin deposits mp-f (Mississippian–Pennsylvanian foreland facies). Area with no pattern is untested. Jurassic (J) evaporites and clastic rocks cover basement of unknown type. Ellipse marking Luling uplift is not intended to demarcate actual area of uplift. See Figure 1 for key to patterns and abbreviations. (c) Surface geology of study area. Also shown are surface projections of two subsurface features: the Lower Cretaceous Comanchean shelf edge (broad patterned line) capped by the Sligo and Stuart City reefs, and 200-m contours on the base of the buried Yoakum Canyon at the Paleocene–Eocene Wilcox shelf edge (after Hoyt, 1959). Heavy black line shows location of COCORP and industry seismic surveys, and open circles show locations of wells with electric logs and cores reviewed in this study. See Figure 1 for key to patterns and abbreviations.

New York, Tennessee, and possibly Arkansas (Culotta et al., 1990; Nelson and Zhang, 1991), integrated with geopotential data and borehole studies (Howe, 1985; Lidiak et al., 1985), suggest that the Grenville province consists of seismically mappable tectonostratigraphic terranes. The Grenville front tectonic zone, separating the Grenville province from the Central Plains province, appears to extend southwestward from western Tennessee, along a path obscured by thick Phanerozoic cover, to the region north of the Llano uplift, where it may be marked by northeast-trending gravity and magnetic anomalies. COCORP plans to continue the Texas survey northward across the Llano uplift in hopes of imaging this boundary and other features related to accretion of the Grenville core of Texas to the rest of the craton.

The boundary between Precambrian Grenville and overlying Paleozoic rocks is known from wells to dip from a depth of 3000 ft (914 m) at the northwest end of line TX6 to 15,000 ft (4572 m) at VP 900 (Meltzer et al., 1972). This intrabasement surface must be extrapolated farther southeast, where it may be imaged on a strike-parallel line segment of TX6 at VP 660–560, 3.0 s., and again at VP 530–430, 4.0 s (Figures 3, 6a). Grenville basement appears to be nonreflective beneath the northwestern half of line TX6. Although probably due to a lack of acoustic impedance contrast caused by pervasive tectonism and metamorphism, this apparent nonreflectivity could be caused by a loss of signal penetration where the line crosses onto outcrops of Cretaceous carbonate rocks (Figures 1, 2c). The boundary between Grenville and Paleozoic basement rocks appears to be further complicated at the southeastern end of TX6, where a series of northwest- and southeast-dipping reflections are traceable to a depth of approximately 25 km (10 s). The origin of these features is discussed in the next section.

PALEOZOIC OUACHITA OROGEN

The upper 1–3 s of basement beneath line TX6 are known from boreholes to consist of late Paleozoic clastic, carbonate, and igneous rocks of the Ouachita orogenic belt (Figures 2–4, 6). The Ouachita orogen is regarded to be a southwestward extension of the Appalachian orogen, and is the result of a Carboniferous–Permian collision between the rifted edge of North America and a volcanic island arc, accreted remnants of which underlie much of the Gulf Coast (Figures 1–2) (King, 1975; Thomas, 1985; Keller et al., 1989). The gross structure of the orogen, known from borehole samples (Flawn, 1961), deep seismic data in Arkansas (Nelson et al., 1982), and gravity data (Lillie et al., 1983), is characteristic of a peripheral foreland thrust belt (Mack et al., 1983).

The Ouachita orogen was divided by Flawn (1961) into a highly sheared and moderately metamorphosed interior zone, and a thrust-faulted but unmetamorphosed frontal zone. Where crossed by the Texas transect, these zones are separated by the Luling overthrust front, a segment of which may be discernible on a strike-parallel segment of line TX6 (Figures 2b, 3). The interior zone includes a belt (unit m-o, Figures 2b, 3) of phyllite, slate, metaquartzite, marble, and schist, and a belt (unit dc-o, Figures 2b, 3) of dark carbonaceous slate with some andesite, basalt porphyry, and granite. These lithologies suggest that the interior zone represents the hinterland or leading edge of the obducted arc. The frontal zone, which extends to the known deformation front near the northwest end of seismic line TX6, contains two distinct assemblages: (1) clastic and carbonate shelf and slope rocks of the Cambrian–Devonian passive margin of North America [unit cd-f (Figures 2b, 3), including parts of the Sauk, Tippecanoe, and Kaskaskia second-order sequences of Sloss (1963), referred to in this paper as

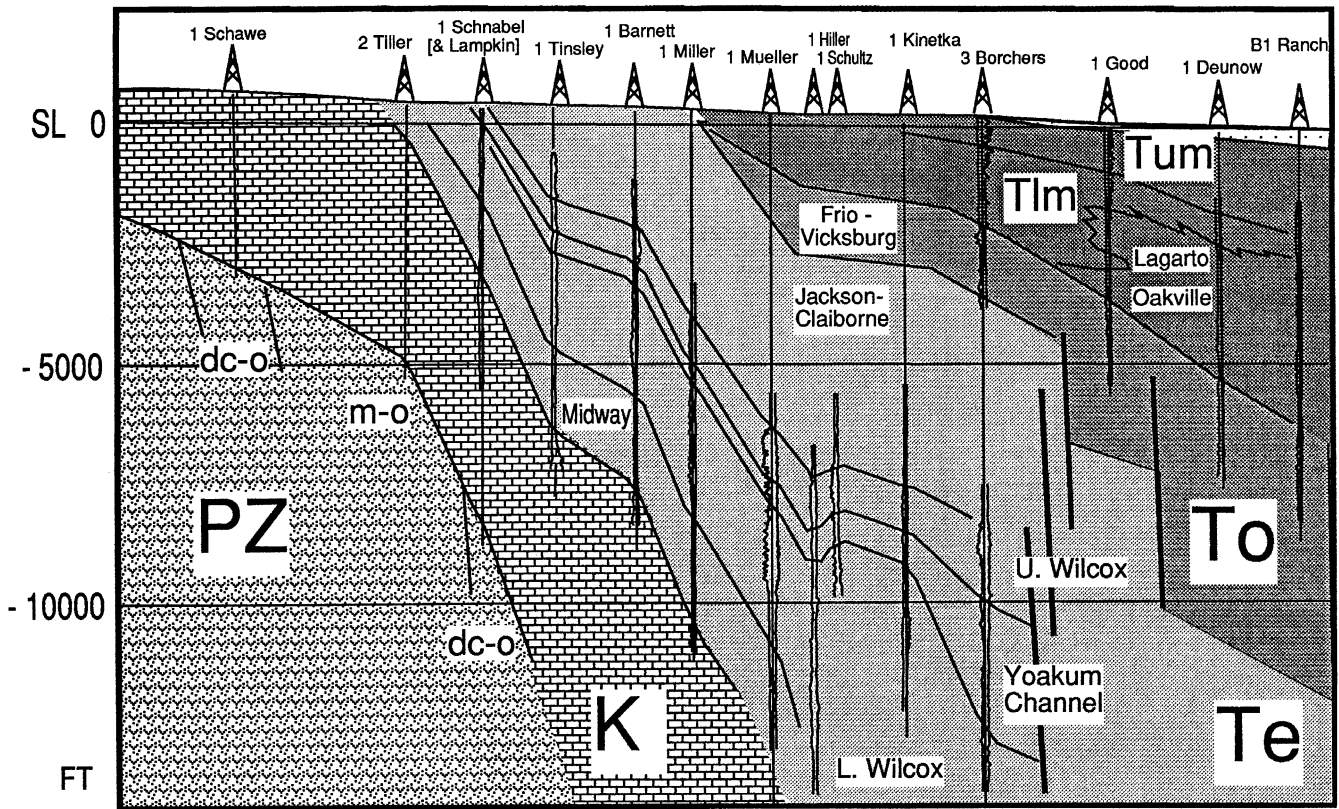


Figure 4—Interpretation of electric logs and cores extracted from a network of published well sections (Flawn, 1961; Bebout et al., 1982; Galloway et al., 1982; Winker, 1982; Morton et al., 1988). Well locations shown in Figure 2. Patterns and abbreviations are the same as those in Figures 1–3, 5. Growth faults are schematic. Note that section roughly parallels seismic survey, including bend in TX5 (from well #3 Borchers to #1 Hiller).

megasequences]; and (2) Carboniferous flysch shed from the collisional orogen into a peripheral foreland basin [unit mp-f (Figure 2b), Absaroka megasequence of Sloss (1963)]. An additional deposit (unit mp-o, Figures 2b, 3), intermediate in geographic location, metamorphic grade, and structural position, consists of flysch with fragments of chert, limestone, granite, schist, and volcanic rock. Of uncertain provenance, this unit appears to depositionally overlie unit cd-f (Figures 2b, 3), and so may represent an offshore facies or arc debris redeposited in a foreland basin.

Luling Uplift

Southeast of the Luling overthrust front, within the interior zone, seismic line TX6 reveals a 50-km-wide, roughly northeast-trending antiform, which we interpret as a basement massif similar to those observed elsewhere along the Ouachita-Appalachian trend (Figures 1–4, 6).

Nearby wells show that the zone of discontinuous subhorizontal reflections above the southeastern flank

consists of dark carbonaceous slate of unit dc-o (Figures 2b, 3, 4, 6). Several wells penetrated metasedimentary rocks of unit m-o above the northwestern flank, and additional slates of unit dc-o appear as far northwest as the Luling overthrust front. We interpret these to be arc-related rocks thrust onto the passive margin along the Luling overthrust and related faults (Figure 3b, c). The reflection geometry on TX6 suggests that this fault system was later folded by formation of the antiform.

The core of the antiform appears not to have been sampled by drilling, but Flawn (1961, p. 170) believed that "...deformation in the interior zone of the Ouachita belt east and south of the Luling overthrust front probably involved [Precambrian] basement rocks, while deformation in the frontal zone was superficial." A similarly situated 60-km-wide antiform imaged by COCORP in Arkansas—the Benton uplift—is thought to be cored by reactivated Precambrian basement and/or accreted arc material (Figure 2a) (Nelson et al., 1982). The Waco and Devils River uplifts elsewhere along the Ouachita trend in Texas, also seismically imaged as broad antiforms, are known to be basement cored (Fig-

ERA	SYS	SER	GROUP	UNIT	AGE (Ma)	
CENOZOIC	TERTIARY	MIOCENE	PLEISTOCENE		0	
			PLOCEENE			
		MIOCENE	U. MIOCENE	GOLIAD	10	
			M. MIOCENE	LAGARTO		
			L. MIOCENE (FLEMING)	OAKVILLE	20	
		OLIGO-CENE	CATAHOULA	FRIO	30	
				VICKSBURG		
		EOCENE	CLAIBORNE	JACKSON	40	
				YEGUA		
				SPARTA		
				QUEEN CITY GARRIZO	50	
		PALEO-CENE	WILCOX	WILCOX	60	
			MIDWAY			
		MESOZOIC	CRETACEOUS	GULFIAN	NAVARRO	70
					TAYLOR	
AUSTIN	80					
EAGLE FORD	90					
WOODBINE						
COMANCHEAN	WASHITA			BUDA	100	
	FREDERICKSBURG			GEORGETOWN		
				EDWARDS		
				GLEN ROSE	110	
				SLIGO	120	
COAHUILA	TRINITY		HOSSTON / SYCAMORE	130		
JURASSIC		COTTON VALLEY	140			
		LOUANN	150			
PALEOZOIC						

Figure 5—Stratigraphy of San Marcos arch (sources cited in text). See Figures 1–4 for key to patterns.

ure 2a) (Nicholas and Rozendal, 1975). The Waco, Devils River, and Benton uplifts, all lying along the Ouachita gravity gradient and structural belt, are interpreted as basement massifs clipped off the upper Paleozoic passive margin and thrust onto the shelf during the Ouachita collision.

In Figure 3, we model the structure on TX6 as a duplexed fault-bend fold, one of several possible interpretations. The floor thrust is assumed to ramp from Precambrian basement into lower Paleozoic platform cover rocks (unit cd-f), as this behavior is observed elsewhere in the Appalachian-Ouachita orogen, and imbrication of these rocks could account for the parallelism and moderate acoustic impedance of these reflections.

Several alternate interpretations hinge on the observation of reflections along the northwestern flank of the antiform extending as deep as 10 s (25 km). On migrated sections (not shown), many of these reflections remain beneath the presumed Precambrian basement surface at 3–4 s (Figures 3, 6). One unlikely possibility is that the deep events are relict Precambrian features that fortuitously align with the antiform flank. Another possibility is that these reflections signify some sort of Ouachita-age tectonic wedge affecting Precambrian basement rocks. [Some of the deeper events are located on a line segment that turns nearly perpendicular to the axis of the San Marcos arch (Figures 1, 2), indicating more complex deformation of Precambrian basement, possibly related to the formation of the arch itself.] A third possibility is that the Precambrian–Paleozoic boundary lies much deeper than 3–4 s (7–10 km, or 4.3–6.2 mi), although the known depth for this boundary at 15,000 ft (4572 m) only 20 km (12.4 mi) to the northwest renders this unlikely.

These hints of Precambrian basement involvement, together with the similar geometry and tectonic context, lead us to believe that the antiform imaged on TX6—hereafter referred to as the Luling uplift—correlates with the Waco, Devils River, and Benton uplifts. Representing the cratonward encroachment of late Paleozoic collision-related deformation, the Luling uplift is broadly akin to the upthrust basement massifs recognized along much of the Appalachian/Caledonide system (e.g., Ando et al., 1984). The Luling uplift thus furnishes a further example of the use of deep seismic data, interpreted in conjunction with geologic and geopotential data, for regional mapping of the three-dimensional structure of crustal terranes.

MESOZOIC–TERTIARY PASSIVE MARGIN

The Ouachita upheaval was followed by a quiescent interval that lasted until the Triassic or Jurassic, when a rift formed more or less along the suture of the accreted Ouachita arc, initiating the present divergent margin regime. The COCORP survey provides an unusually

complete image of the onshore Texas part of the Mesozoic–Cenozoic passive margin wedge (Figures 3, 5, 7, 8), although we emphasize that the resolution of some individual features may be lower than that of more localized industry studies. The strata are arrayed in a series of offlapping transgressive-regressive depositional sequences (Galloway, 1989), which we have identified by correlation with a net of nearby electric logs (Figures 2–4), industry seismic lines, and outcrops, and displayed in line drawing form on Figure 3. The shelf and upper slope parts of several of these sequences are shown in detail on Figures 7 and 8, bounded by Lower Cretaceous clastic and carbonate rocks of the Trinity and Edwards sequences; and the Paleocene–Eocene Midway and Wilcox, Eocene Jackson–Claiborne, and Oligocene Vicksburg and Frio clastic sequences.

Our discussion will focus on five features that illustrate particular aspects of the evolution of this passive margin: (1) a possible rift-related graben, (2) evidence of reactivation of the Ouachita antiform as a hingeline, (3) a possible Lower Cretaceous shelf-edge embayment or canyon, (4) the Paleocene–Eocene Yoakum Canyon, and (5) the growth-faulted shelf edges of the Tertiary sequences.

Rift Phase

A strong, fairly continuous event on seismic line TX5 (black horizon on Figure 7), dipping from 2.8 s at VP 980 to 4.2 s at VP 640, probably correlates with the top of Paleozoic basement on line TX6. Sloss (1963) recognized this surface as part of a continent-wide unconformity separating the Carboniferous to Lower Jurassic Absaroka megasequence from the overlying Jurassic to Paleocene Zuni megasequence. The basal deposits of the Zuni megasequence in this region are Jurassic evaporites and clastic rocks, which pinch out updip near VP 800 on TX5 (Figures 1, 2b, 3, 5, 7) (Budd and Loucks, 1981). These rocks were deposited during rifting and attenuation of the previously accreted Ouachita crust, as shown by gravity and seismic refraction data (Lillie et al., 1983; Buffler and Sawyer, 1985).

Although a main reason for siting the COCORP transect along the San Marcos arch was the hope that its relatively thin Jurassic salt and later sediment cover might permit sufficient signal penetration to image the rifted Paleozoic basement, only a few sub-Cretaceous reflections were recorded seaward of the Ouachita antiform. Sharply bounded packages at VP 720–620 and 480–400 may represent dip- and strike-parallel sections through a single fault-bounded graben (Figure 7). Strong southeast-dipping events between VP 650–1000 at 6–8 s (not shown) appear to be multiples of the overlying Cretaceous carbonate layer, although other events at 9–10 s could be continuous with the southeastern flank of the Luling uplift (Figure 1).

Reactivation of Ouachita Structure as a Hingeline

Several lines of evidence indicate that the influence of Ouachita structures on the architecture of the margin may have persisted beyond the early Mesozoic rifting stage into the Tertiary, or even to the present (Caran et al., 1982). Whereas Cretaceous carbonates of the Zuni megasequence overstep the rifted margin far north and west of the Llano region, the seaward-thickening Oligocene and younger clastic deposits of the Tejas megasequence lap out near the apex of the Luling uplift (Figures 1–4, 6). The original extent of the intervening Paleocene–Eocene section is unknown because it was erosionally beveled just northwest of the Luling uplift. Cutting these Cretaceous to Tertiary strata are steep faults (Luling fault zone), some of which dip to the northwest, counter to the general regional pattern of down-to-the-basin faulting. A series of conjugate normal faults imaged on line TX6 appears to sole into the surface of the Luling uplift (Figures 1–3, 6). These faults are part of the regional Luling–Mexia–Talco fault system, which follows the Ouachita interior zone northward to the Waco uplift (Figure 2a) and also coincides with an inflection in the modern surface, changing basinward from 16 to 8 ft/mi (3.1 to 0.94 m/km) (Flawn, 1961). These faults do not sole into the Jurassic salt, the northwest limit of which is 40 km southeast of the fault zone (Figure 2b). These observations suggest that the Luling uplift and related Ouachita structures were reactivated in the middle Tertiary, and are in some way related to the hinge of the subsiding Gulf Coast passive margin (Miser, 1934).

A similar origin may be ascribed to the adjacent Balcones fault zone (Figures 1–2), which closely follows the Ouachita frontal zone before dying out to the southwest, and along which are emplaced a number of otherwise enigmatic Upper Cretaceous igneous intrusions (Caran et al., 1982). Winker (1982) noted that flexural support of the sedimentary load would lead to the formation of a peripheral bulge that would function as a hinge. The location and magnitude of the bulge might be influenced by preexisting mechanical anisotropies in the basement, such as the Ouachita antiform. Such an anisotropy could function as a second-order hinge even when the principal bulge is located elsewhere.

Comanchean-Sligo Reef, Trinity Canyon, and Stuart City Reef

Line TX5 crosses the edge of the Cretaceous Comanchean carbonate shelf (Figures 2c, 3, 7). Siemers (1978) related the location of this shelf edge to a preexisting basement structure, the Caldwell–Angelina flexure; and Muehlberger and Land (1988) interpreted geopotential and refraction data to indicate an underlying continent-ocean crustal transition.

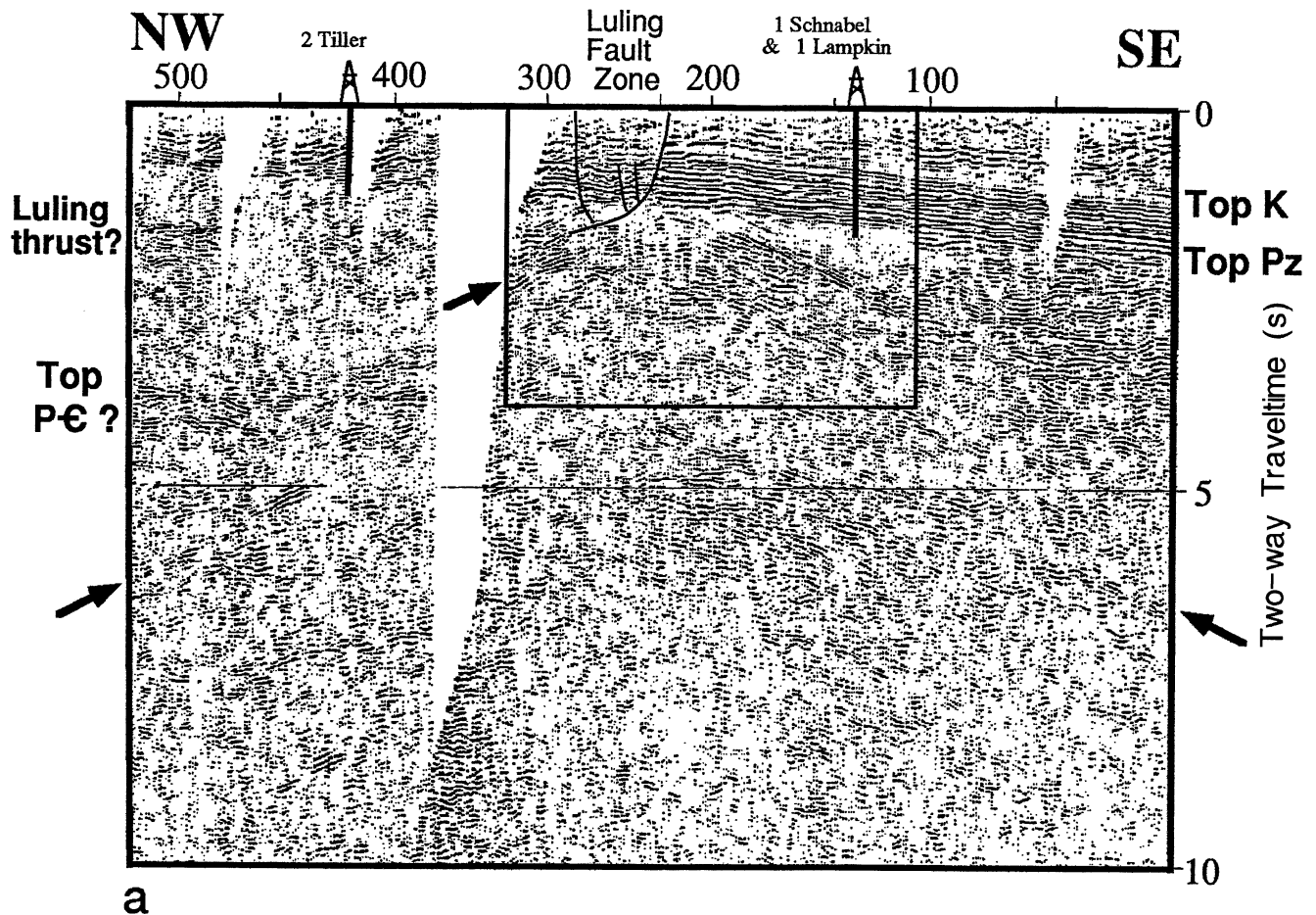


Figure 6—(a) Part of line TX6 showing 50-km-wide Luling uplift within the interior zone of the Ouachita structural belt. See Figures 1–3 for location of line TX6. Arrows indicate upper surface of antiform. Wells do not sample core of uplift, which may be a detached slice of Precambrian basement. Also marked are presumed top of undisturbed Precambrian basement at VP 430–530, and the flat segment of the Luling overthrust front, which subcrops 20 km to the northwest (see Figure 2). Box shows area enlarged in (b). (b) Detail of the crest of the Luling uplift on TX6, showing normal faults of Luling fault zone cutting strongly reflective Cretaceous carbonate and overlying lower Tertiary clastic strata.

On the carbonate shelf across the San Marcos arch, Lower Cretaceous rocks can be divided into the clastic and carbonate Coahuila series (including the Hosston and Sligo formations of the Trinity Group) and the carbonate Comanche series (Edwards Formation among others) (Figure 6) (Rose, 1972; Winker and Buffler, 1988). Above the Paleozoic Ouachita sequence and possible rift fill (black horizon, Figure 7) on TX5, between VP 550–800 and 2.5–4.0 s, is a series of three clinoformal reflection packages that prograde successively eastward, ending in a steep topographic break (drab green horizon) which, in turn, is onlapped by a series of lenticular moundy packages. These sediment packages have position, form, and seismic character similar to the Hosston-Sycamore sandstone and the lower and upper Sligo reefs of the lower Trinity Group

(Figure 6) (Siemers, 1978; Winker et al., 1983; R. W. Scott, 1990, personal communication).

The simplest interpretation of these Trinity Group reflection geometries is that the topographic break (drab green horizon, Figure 7) marks a former shelf edge where clinoformal shelf-slope deposits are onlapped by hummocky mounds of forereef talus or other off-shelf deposits; however, the orientation of this segment of line TX5 nearly parallel to strike appears to require that the topographic break represent an embayment in the Lower Cretaceous shelf edge. This observation invites a second, more speculative interpretation: this embayment is the mouth of a shelf-edge canyon 2 km deep and more than 15 km wide, about the same scale as the modern Monterrey Canyon. Amsbury (1974) predicted, based on regional geologic relations,

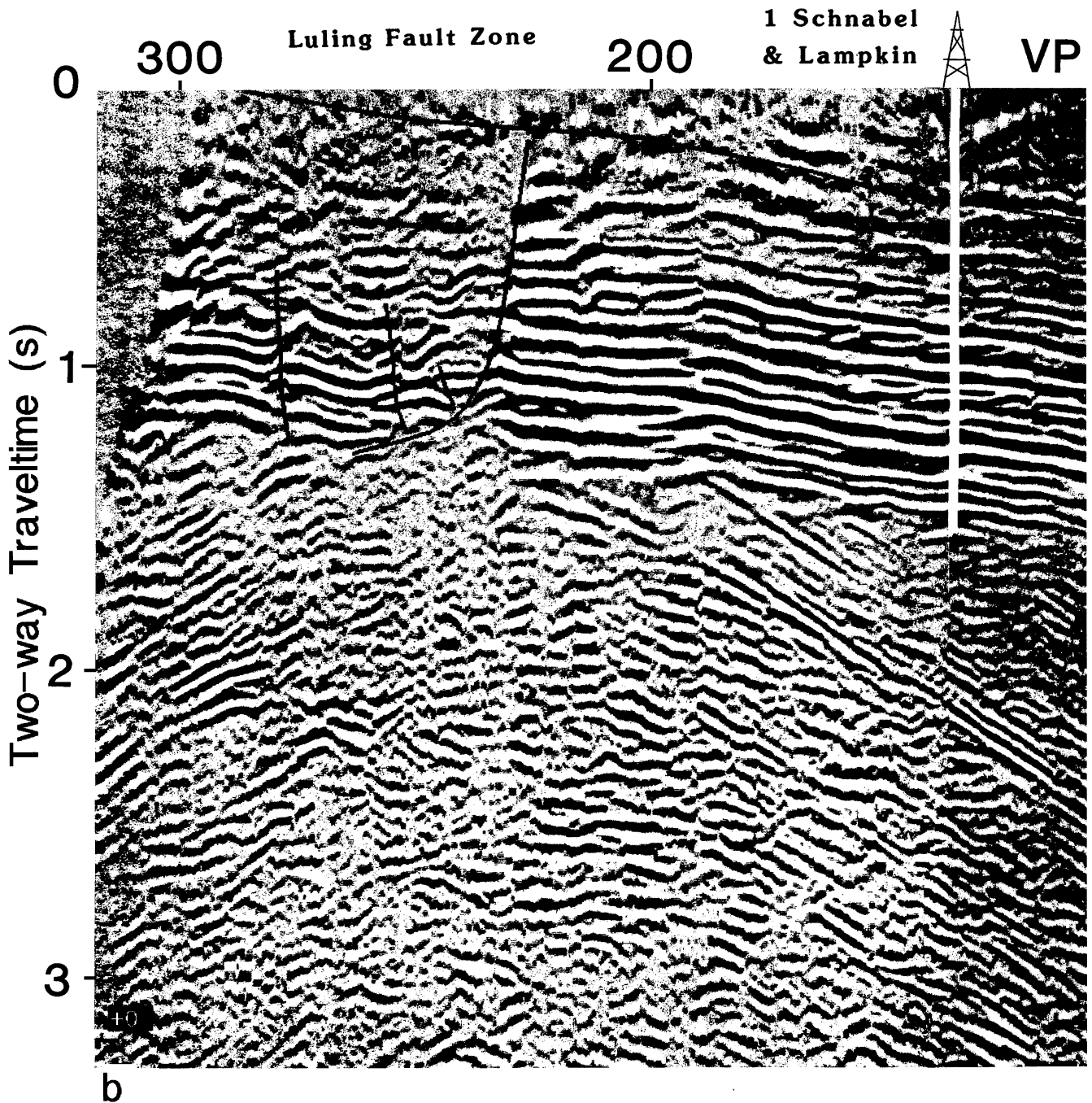


Figure 6—Continued.

the existence of such canyons on this part of the Texas coast during the middle of Trinity Group deposition, reasoning as follows. The basal deposits of the southeastward-thickening lower Trinity Group (Coahuila Series)—the coarse, fluvial, terrigenous Hosston-Sycamore sandstone—were carried onto the San Marcos arch by southeastward-flowing rivers from sources

on the continent. The lower Trinity Group Sligo limestone was conformably deposited above the Hosston-Sycamore sandstone. A profound disconformity was then cut on top of the lower Trinity rocks. The succeeding transgressive middle Trinity rocks deposited on this surface include only minor terrigenous alluvial components, which were also shed southeastward

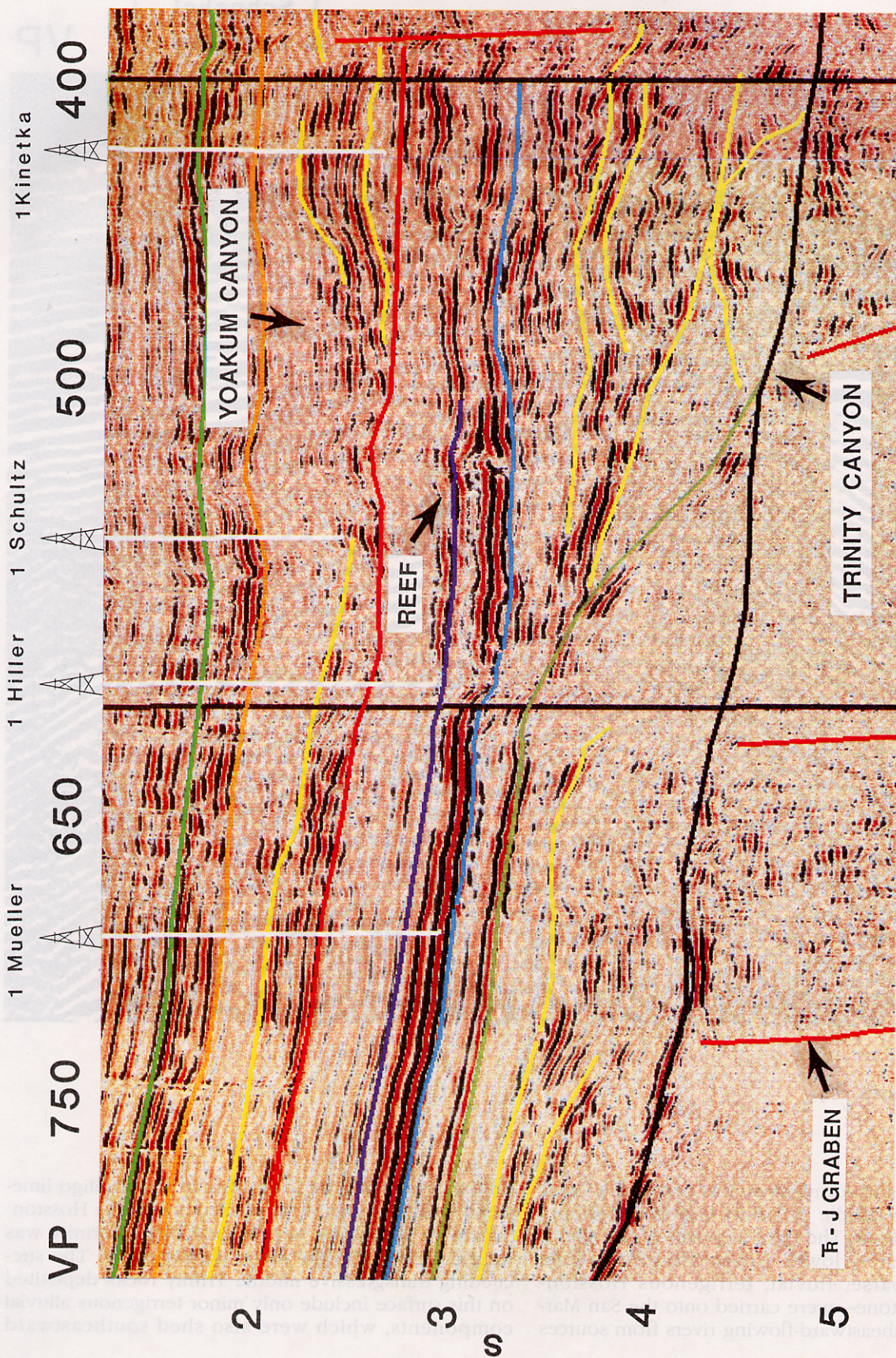


Figure 7—Detail of line TX5 (location shown on Figure 3) shown as on a Landmark™ workstation. Vertical exaggeration is approximately 3.5:1. Colored horizons represent boundaries of major depositional sequences: Lower Cretaceous Trinity (black to light blue); Lower Cretaceous Edwards (light blue to dark blue); Paleocene-Eocene Midway (dark blue to red) and Wilcox (red to bright green); Eocene Jackson-Claiborne (above bright green). Yellow horizon segments mark facies and systems tracts boundaries. Growth faults are representative, as in Figure 3. For location and interpretation of electric well logs see Figures 2-4. Time is two-way traveltime in seconds.

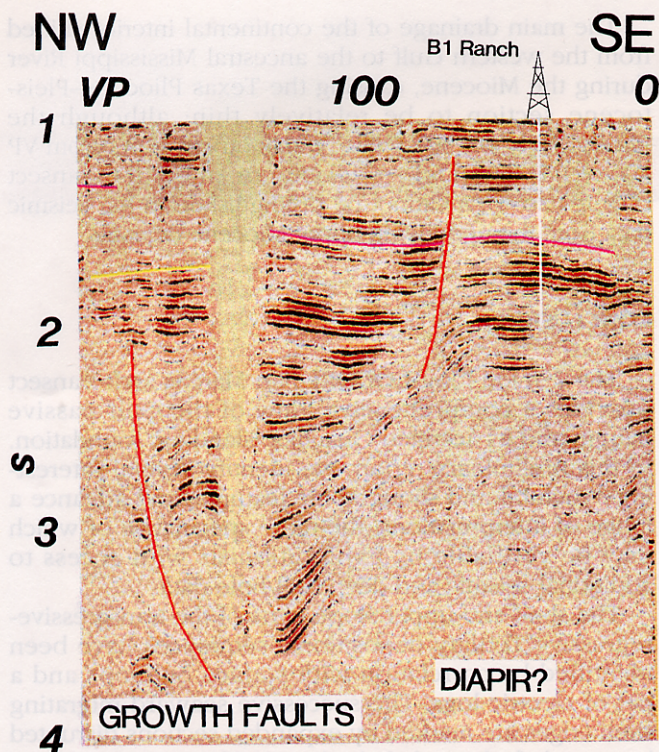


Figure 8—Part of line TX4 (location on Figure 3) showing fault-flanked diapir and expanded section at Vicksburg-Frio shelf edge. Colored horizons bound Oligocene Vicksburg-Frio (violet to pink), and lower Miocene Fleming (above pink) sequences. Diapir is cored by geopressured shale, or possibly salt. Vertical white line shows location of well #B1 Ranch. Time is two-way traveltime in seconds.

from the continental interior. Proximal upper Trinity rocks again include significant clastic deposits. Amsbury (1974, p. 32-33) found it unlikely that

...several streams large enough to supply the Sycamore-Hosston terrigenous material would dry up completely and cease flowing throughout the time required to form a regional disconformity and then deposit the Middle Trinity sediments.... The streams may have become entrenched into narrow canyons across the shelf, so that the clastic material carried by the streams was dumped southeast of the area studied. Narrow canyons could lie undetected between the sparse core-holes and wells.... [Such] localized bodies of coarse terrigenous material deposited within fine-grained material on or southeast of the Middle Trinity carbonate shelf could be very attractive hydrocarbon reservoirs.

Not knowing whether the shelf-embayment imaged on COCORP line TX5 has also been imaged in unpublished industry data, we can only suggest that it has the right age, shape, fill geometry, and location to warrant

further investigation of the possibility that it is a major Lower Cretaceous shelf-edge canyon, here tentatively named Trinity Canyon. Further circumstantial support for this interpretation is found in the lower Tertiary rocks, described in a following section.

The Comanchean shelf edge is capped by the Stuart City reef, a part of the Lower Cretaceous Edwards Formation (Figures 2c; 3; 5; light blue to dark blue horizons on Figure 7). The Stuart City reef is clearly imaged as an anomalously high-amplitude, mounded feature at VP 500–600. Mimicking of its mounded shape in the overlying sediments may be due to differential compaction because deeper reflections are flat, and this segment of the line is relatively straight.

A straightforward sequence stratigraphic interpretation of the entire Cretaceous Coahuila-Comanche series might be as follows: the lower Trinity Group was deposited during one cycle of lowstand, transgression and highstand; falling sea level then produced a sequence-bounding unconformity across the upper Sligo shelf (drab green horizon, Figure 7), and middle Trinity clastic sediment bypassed this shelf through the deep Trinity Canyon, to be deposited on the slope as onlapping debris flows or turbidite fans; the overlying upper Trinity Glen Rose Limestone and Hensel Sandstone (between drab green and light blue horizons) then transgressed the middle Trinity unconformity; the Stuart City reef (light blue to dark blue horizon, Figure 7) built back seaward during highstand; then the Washita and other Upper Cretaceous units were deposited before falling sea level at the end of the Cretaceous produced the major unconformity separating the Jurassic–Cretaceous Zuni megasequence from the overlying Paleocene–Holocene Tejas megasequence (Sloss, 1963).

Tertiary Clastic Sequences

The oldest subdivision of the Tejas megasequence is the Paleocene–Eocene Midway-Wilcox sequence. On the San Marcos arch, prograding clinofolds of the mud-rich Midway formation grade up into the sandy Rockdale delta system in the lower Wilcox. The southwestern flank of this delta is incised by the 900-m-deep Yoakum Canyon, filled with middle Wilcox shales (Hoyt, 1959; Winker et al., 1983; Galloway et al., 1990) (Figures 2c, 3–5). Line TX5 parallels the Yoakum Canyon from the northwest end to VP 620, where it bends sharply northeastward across the bank of the canyon mouth (Figures 2c, 7). At VP 400, the line turns southeastward again, running down the canyon axis and over the Wilcox shelf edge, where the section is expanded and disrupted by growth faults.

The situation of the Trinity Canyon directly beneath the Yoakum Canyon may be more than coincidental. Because the Yoakum Canyon was a principal pathway of sediment delivery from the Laramide orogen to the Gulf (Galloway et al., 1990), it might be reasonable to

suppose that the earlier, deeper Trinity Canyon was also carved by a river from within the continental interior. Alternatively, erosion of both canyon systems may have been largely accomplished by a combination of persistent submarine currents and shelf-edge slumping (D. L. Amsbury, 1990, personal communication; Galloway et al., 1990).

Above the Wilcox is the Eocene Jackson-Claiborne sequence (Figures 3–5; above bright green on Figure 7), which transgressed as far as the narrow outcrop belt at VP 100 on line TX6 before gradually prograding southeastward beyond the Wilcox shelf edge to around VP 50 on line TX5. Diminished stratigraphic continuity beyond the Jackson-Claiborne shelf edge at VP 50 is probably due as much to growth faulting as to gaps in the data (Winker, 1982) (Figures 3, 7).

Better displayed is the growth-faulted shelf edge of the Oligocene Vicksburg-Frio sequence on line TX4 (Figure 3; violet to pink horizons, Figure 8). These rocks have a narrow outcrop belt around VP 900 on TX5. The growth faults imaged from VP 150–350 on TX4 occur within the Vicksburg-Frio expansion zone (Figures 3, 4, 8). TX4 also images a fault-flanked diapiric structure that resembles the coast-parallel ridges cored by geopressed Vicksburg and Frio deep-water shales northeast and southwest of the study area (Figure 1) (e.g., Ewing, 1986), although such features previously have not been reported onshore in the transect area. A drill hole bottoming in Frio shale (Figures 3, 4, 8) (Galloway et al., 1986) penetrated the top of the diapir, but perhaps not its core; although salt domes are rare in this area, Loucks et al. (1986) reported that a diapir in approximately this location may be salt cored.

The lower Miocene Fleming (Oakville-Lagarto) sequence crops out from VP 650 to 930 on line TX5 (Figures 2c, 3, 4) (Galloway et al., 1986). At its base is the transgressive Anahuac marine shale. Prograding seaward are lagoon mudstone and shore-zone sand (mostly Oakville Formation), followed by fluvial-delta plain sand and mudstone (mostly Lagarto formation). The boundary between the fluvial-delta plain facies and the underlying units (Figures 3, 4) is evident where highly reflective strata onlap a less reflective unit on TX4 and VP 1–200 of TX5, then overstep the lower sequence boundary on line TX5 from VP 150–500. Growth faulting at the lower Miocene shelf edge begins near the southeastern end of TX4, producing an enormously thickened slope section offshore (Figure 1).

Unconformably overlying the lower Miocene Fleming sequence is the middle–upper Miocene Goliad sequence (Figures 3–5) (Morton et al., 1988). Where it crops out from VP 300 to 650 of line TX5, the Goliad Formation consists of mostly nonmarine fluvial plain deposits. This sequence appears as a low-amplitude wedge of reflections extending off the southeastern end of TX4, where the combined upper and lower Miocene underlies much of the modern continental shelf and slope (Figures 1, 3).

The main drainage of the continental interior shifted from the western Gulf to the ancestral Mississippi River during the Miocene, causing the Texas Pliocene–Pleistocene section to be relatively thin: although the Pliocene–Pleistocene Willis Formation crops out from VP 300 of line TX5 to the southeastern end of the transect (Figures 2c, 4), it cannot be distinguished in the seismic data from the underlying upper Miocene deposits.

CONCLUSIONS

The 250-km-long COCORP San Marcos arch transect provides a comprehensive view of the Gulf passive margin and its accreted Ouachita island-arc foundation. In this preliminary report, we identify several interesting structural and stratigraphic features, and advance a range of interpretations, the more speculative of which may be verifiable by explorationists with access to additional seismic and deep drill-hole data.

The shelf and upper slope parts of the transgressive-regressive Tertiary depositional sequences have been identified by correlation with surface outcrops and a net of electric logs. The successive seaward migrating shelf edges are marked by expanded sections disrupted by growth faults and shale diapirs. The transect crosses the mouth of the 900-m-deep Yoakum Canyon within the Paleocene–Eocene Wilcox sequence. The underlying Lower Cretaceous Stuart City reef appears as an anomalously high-amplitude mound capping the Comanchean shelf edge. We speculate that an apparent embayment in this Cretaceous shelf may be a submarine canyon older, deeper, and perhaps ancestral to the Yoakum Canyon. In addition to its potential economic interest, the existence of such a canyon raises the possibility that the drainage system from the continental interior to the northwestern Gulf was established earlier than previously recognized.

A prominent antiform imaged within the Ouachita interior zone is interpreted as the leading edge of the obducted Ouachita arc, possibly overlying a detached core of Grenville basement. This Luling uplift is located beneath the updip limit of the Cenozoic sediment wedge, which is cut by steeply dipping normal faults that sole into the top of the uplift. These faults are part of a regional fault system that coincides with a pronounced gravity gradient and an inflection in surface slope, and that permits correlation of the Luling uplift with the similar Devils River, Waco, and Benton uplifts far to the southwest and northeast. Tertiary reactivation of this extensive Ouachita structure suggests that it has functioned as a hingeline to the subsiding passive margin.

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